TECHNICAL NOTE

D-375

A MANUAL FREQUENCY SWEEP TECHNIQUE FOR THE MEASUREMENT OF AIRPLANE FREQUENCY RESPONSE

By Harold L. Crane

Langley Research Center
Langley Field, Va.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
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SUMMARY

A brief evaluation has been made of a method for the determination of longitudinal airplane frequency-response characteristics from a manual frequency sweep input. The test runs were made by cycling the longitudinal control with continually varying frequencies from approximately 1/3 to 3 cycles per second. The sweep input was followed by an interval with the control fixed to permit the transient response to damp out. Time histories of input and response quantities were transformed into frequency-response form on a digital computer. The results show that, compared with the relatively satisfactory triangular-pulse input, for example, a manual frequency sweep input provides a high level of input frequency content over a broader band of frequencies. However, the samples obtained with this type of input were subject to bottoming at and below the short-period resonant response frequency and sometimes resulted in uncertain definition of the frequency response at the lower frequencies.

INTRODUCTION

The usual methods for airplane frequency-response determination require either extensive flight testing (with the use of the steady-state harmonic excitation technique described in ref. 1) or extensive data reduction (with the use of pulse or step inputs as described in ref. 2). In addition, the inputs in the latter category are likely not to provide adequate harmonic content over the whole frequency range of interest and, as a result, the frequency-response data obtained may become uncertain at the higher frequencies. As mechanized data reduction methods are developed further, the time required for deriving frequency response by the methods of reference 2 will be less significant; however, it would be desirable to find a method of excitation that more consistently provides adequate input power over the frequency range of interest.

This paper describes the application of a manual frequency sweep technique designed to provide a high level of harmonic input content over the frequency range of interest in regard to longitudinal aerodynamic response modes (2 to 20 radians per second in this case). The frequency sweep results are compared with frequency-response data obtained from triangular-pulse inputs and manual constant-frequency inputs.

SYMBOLS

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A_n	modulus of Fourier transform of normal acceleration
$A_{\dot{\theta}}$	modulus of Fourier transform of pitching velocity
A_{δ_1}	modulus of Fourier transform of stabilizer deflection
a_n	normal acceleration, g units
F	longitudinal control force, lb
δ_1	stabilizer deflection commanded, deg
δ_2	stabilizer deflection, deg
$\dot{\theta}$	pitching velocity, radians/sec
Φ_n	phase angles for normal acceleration, deg
$\Phi_{\dot{\theta}}$	phase angles for pitching velocity, deg
ω	circular frequency, radians/sec

INSTRUMENTS

Standard National Aeronautics and Space Administration photographic instruments were used for this investigation. The instruments were accurate to within 2 percent of the scale range. The frequency responses of the various instruments were approximately equal and had a natural frequency of 10 cycles per second and a damping ratio of 0.65. Pertinent measured quantities with scale ranges and instrument sensitivities were as follows:

Quantity	Scale range	Sensitivity per inch of trace deflection
Longitudinal control force, F, lb . . .	±60	60
Stabilizer deflection commanded, δ_1, deg	4 to -18	10
Stabilizer deflection, δ_2, deg	4 to -18	10
Normal acceleration, a_n, g units . . .	0 to 3.3	1.56
Pitching velocity, $\dot{\theta}$, radians/sec . . .	±0.5	0.5

All instrument records were synchronized by timer markings at 1/10-second intervals. The stabilizer position recorder failed during this investigation. However, frequency-response data for the control system obtained from previous measurements by the pulse technique are presented to make it possible to reconstruct the missing stabilizer position data in terms of frequency response.

DESCRIPTION OF TECHNIQUE

Sampling Method

Samples of frequency sweep data were obtained in the following manner. The pilot was requested to cycle the stick fore and aft at frequencies which varied from 1/3 cycle per second to 3 cycles per second in such a manner as to produce appreciable longitudinal airplane response over this frequency range. This input was to have a maximum duration of 10 seconds and be followed by a 10-second interval with the stick at the trim position to permit the airplane response to damp out. About 10 samples were obtained as a portion of one research flight. It was necessary in the present tests to limit the length of the test samples to keep both the manual readout and the digital computer time per test run within reasonable limits.

Data-Reduction Procedure

Time histories of control force F, control position δ_1, and the airplane response quantities, pitching velocity $\dot{\theta}$ and normal acceleration a_n, were determined from continuous instrument records at 1/10-second intervals up to a maximum of 200 intervals per sample. The transformation to the frequency plane was made at frequency intervals of 0.4 radian per second with a digital computer by using the Fourier methods and the conveniently tabulated functions of references 3 and 4. On the basis of previous experience with this type of sampling, it was believed that an adequate indication of the frequency content of the sample would be obtained at frequencies up to at least 2.5 cycles per second (approximately 16 radians per second).

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RESULTS AND DISCUSSION

A typical time history of one manual frequency sweep input and the airplane response including the transient oscillation with control fixed are shown in figure 1. These runs were made at 35,000 feet and at a Mach number of 0.85 with a small swept-wing transonic fighter airplane. The measured variables for which the Fourier transforms of the measured time histories are desired are control force F, stabilizer position called for δ_1, control surface position δ_2, pitching velocity $\dot{\theta}$, and normal acceleration a_n. Typical transforms of the input quantity δ_1 are presented to show the content of the input as a function of frequency. Transfer functions of interest are δ_1/F, δ_2/δ_1, $\dot{\theta}/\delta_2$ or $\dot{\theta}/\delta_1$, a_n/δ_2 or a_n/δ_1, $\dot{\theta}/F$ and a_n/F. However, for the test airplane with its standard control system the force variation with control surface deflection can only be considered to be linear for approximately $\pm 1^{\circ}$ from the trimmed position. Therefore, the transfer functions which involved control force are likely to be distorted by this nonlinearity and are not presented.

A plot of the frequency response of the control system determined from previous measurements by the pulse technique is shown in figure 2 for the frequency range of interest (ω from 0 to 20 radians per second). The amplitude response fell off gradually by about 20 percent and the lag built up gradually to approximately 45° over this frequency range. This response corresponds to a damping ratio close to unity.

In figures 3 and 4 examples of frequency-response results from two of the manual sweeps are shown and compared with results from triangular-pulse and manual constant-frequency inputs. Figures 3(a) and 4(a) present the moduli of Fourier transforms of the input δ_1 and of the output $\dot{\theta}$ or a_n, and figures 3(b) and 4(b) present the amplitude ratio and phase angle of the transfer functions $\dot{\theta}/\delta_1$ or a_n/δ_1 for circular frequencies up to 20 radians per second. The frequency content of the manual sweep input is seen to be considerably higher than that of the triangular pulse particularly for the upper half of the frequency band considered. Input content data for the manual constant frequency runs are also shown in figures 3(a) and 4(a) as simple input and output amplitudes.

A mechanically driven frequency sweep of constant amplitude in which the frequency is varied gradually at a constant rate is known to have constant harmonic content except near the end points of the frequency interval. The manual sweeps from 2 to 20 radians per second were irregular in both amplitude and sweep rate. In addition, the limitation of usable sample lengths required that the sweep rate be very rapid at frequencies of approximately 6 radians per second or less. However, if the short-term irregularities are faired out, the frequency contents of the manual sweep runs of figures 3(a) and 4(a) were found to vary gradually by not more than a factor of two between frequencies of approximately 4 and 18 radians per second.

The raggedness of the sweep input which is apparent at frequencies above 6 radians per second is as large, percentagewise, in the indicated airplane response and is probably caused to a large extent by the finite number of intervals considered with a frequency interval of 0.4 radian per second. However, this raggedness of the moduli did not occur for all runs and is much less evident in the amplitude ratio or phase of the transfer functions.

The frequency-response results as shown in figures 3(b) and 4(b) from the three types of input are in rather good agreement except at circular frequencies below 1 radian per second and near the airplane short-period resonant frequency. The quality of the results from the manual sweep run is poor in the vicinity of the resonant frequency partly because the pilot did not excite the oscillation at this frequency. It might be possible for the pilot to increase his power input at resonance enough to obtain more acceptable frequency-response data without endangering the aircraft structure. However, the lower quality of the frequency sweep results at frequencies below approximately 5 radians per second was considered to be in large part due to the effects of the short duration of the samples. As stated previously, the duration of the inputs was limited to 10 seconds to facilitate the data reduction. This procedure limited the number of input cycles particularly at the low frequencies of less than approximately 1 cycle per second and often resulted in very erratic frequency content in this range of frequency.

The frequency-response results from these methods tend to become indeterminate at zero frequency; however, a step input run can readily be used to get this one point. By using a step input, a_n/δ_1 was found to be 0.7g/deg and $\dot{\theta}/\delta_1$ was found to be 0.03 radian/sec/deg at

$\omega = 0$ for the test airplane (at a Mach number of 0.85 and an altitude of 35,000 feet).

It was also found that in this case the frequency-response measurements using sweep or pulse inputs tend to yield indeterminate results whenever the input frequency content falls below a level of approximately 0.3 deg-sec. Within the intended frequency range of the frequency sweep inputs, this effective bottoming, when it occurred, was usually for a small frequency interval and therefore caused a spike on the amplitude ratio and/or phase angle plot. An illustrative example is presented in figure 5.

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The triangular pulses of figures 3 and 4 were designed to have a duration of 1 second for which the theoretical bottoming frequency, as shown in reference 2, for example, would be at $\omega = 12$. However, triangular inputs of 1/2-second duration with adequate power content could probably be obtained with the test airplane. In that case the bottoming frequency would be raised to a circular frequency of at least 20 radians per second.

A usable example of a more abbreviated sweep run with a 5-second input was found among the test samples; this run was reduced in conjunction with a 5-second transient interval. The results are presented in figure 6. The data-reduction time for this sample was reduced nearly 50 percent and the results were found to be satisfactory for circular frequencies above approximately 3 radians per second. In general, however, the results from such a brief sample would be likely to be more erratic at the lower frequencies.

CONCLUDING REMARKS

The results of this investigation indicate that a manual frequency sweep is a suitable input for obtaining the longitudinal frequency response of an airplane. The frequency content of the input showed a desirable tendency to stay at a uniformly high level up to the maximum frequency considered. However, the samples obtained with this type of input were subject to bottoming at and below the short-period resonant response frequency and sometimes resulted in uncertain definition of the frequency response at the lower frequencies.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Field, Va., February 1, 1960.

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3. Donegan, James J., and Huss, Carl R.: Comparison of Several Methods for Obtaining the Time Response of Linear Systems to Either a Unit Impulse or Arbitrary Input From Frequency-Response Data. NACA Rep. 1324, 1951. (Supersedes NACA TN 3701.)

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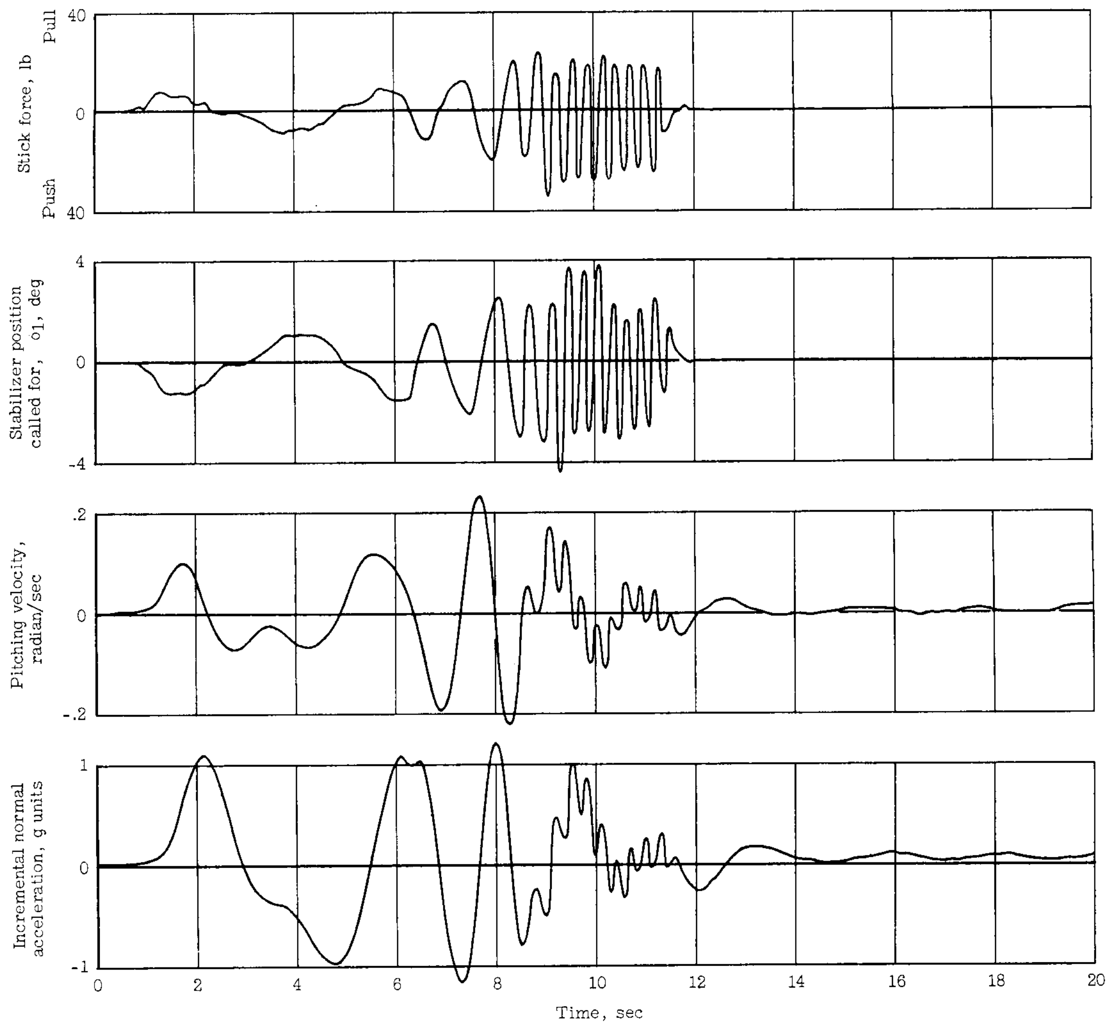

Figure 1.- Time history of a manual frequency sweep run made at an altitude of 35,000 feet and a Mach number of 0.85.

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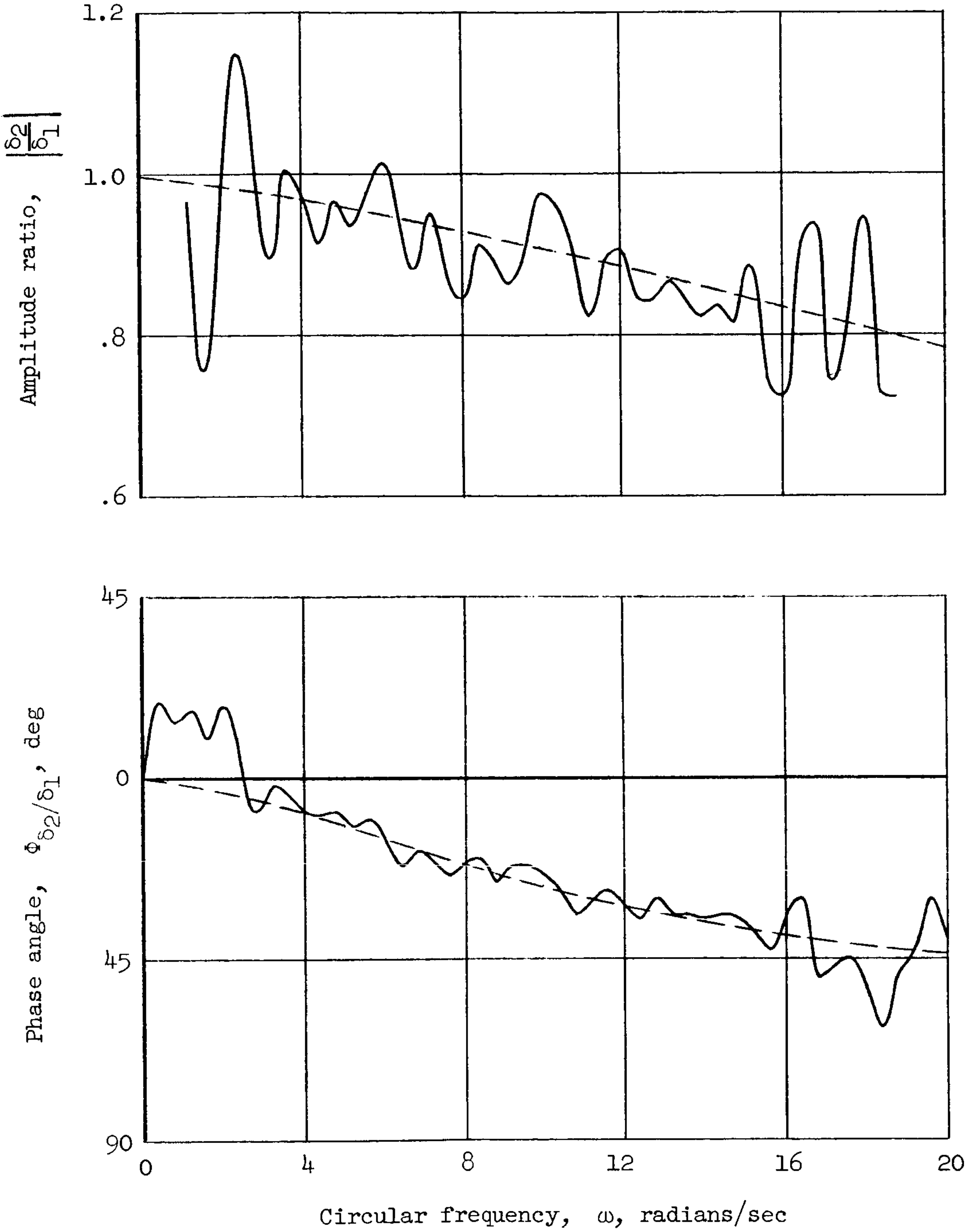
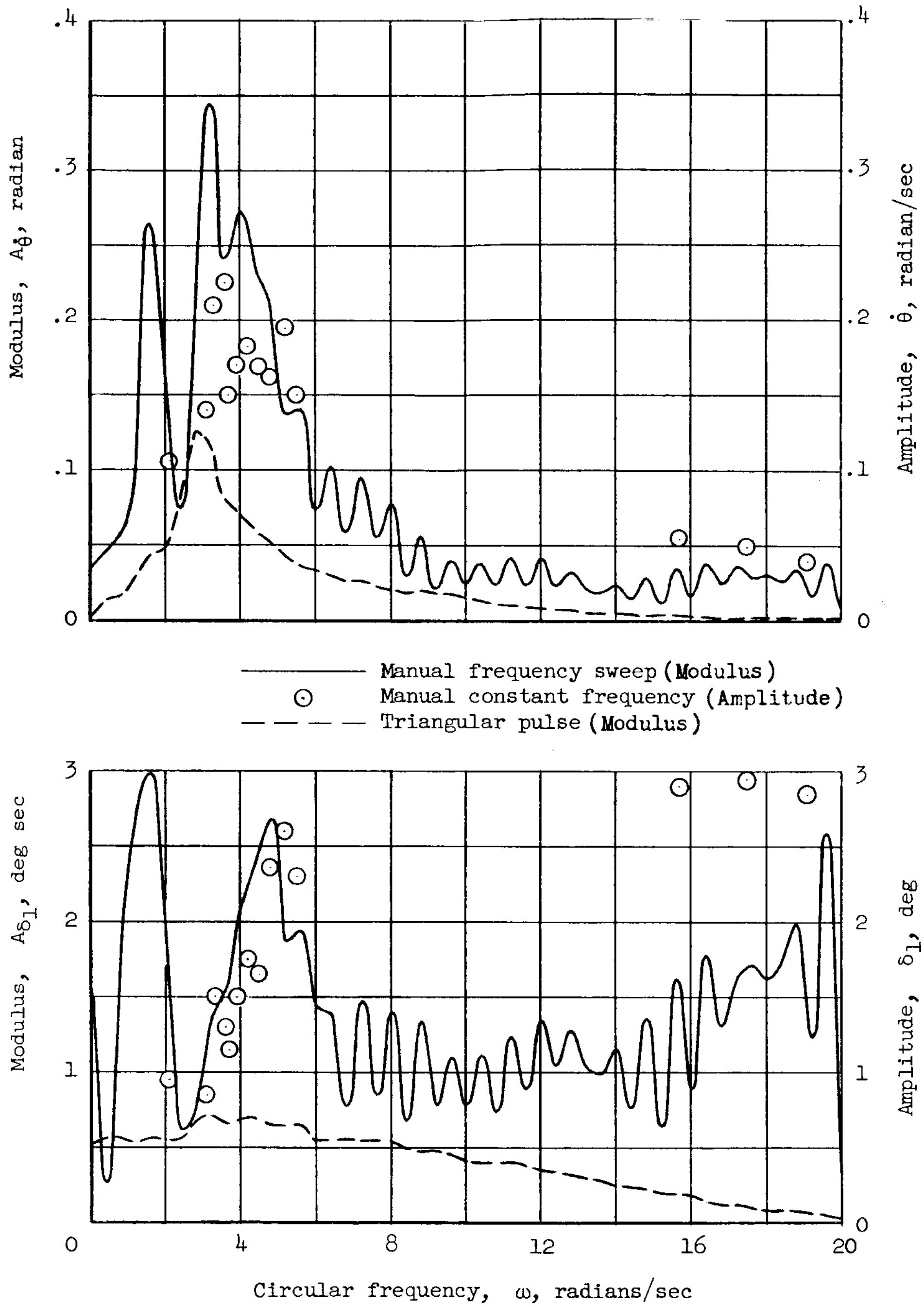


Figure 2.- Measured control system frequency response for the test airplane. (The dashed line represents a fairing or smoothing of the raw results.)



(a) Harmonic content of input and output.

Figure 3.- Frequency response in pitch of the test airplane at a Mach number of 0.85 and an altitude of 35,000 feet calculated from the time history of figure 1 and compared with results from steady-state and triangular-pulse inputs.

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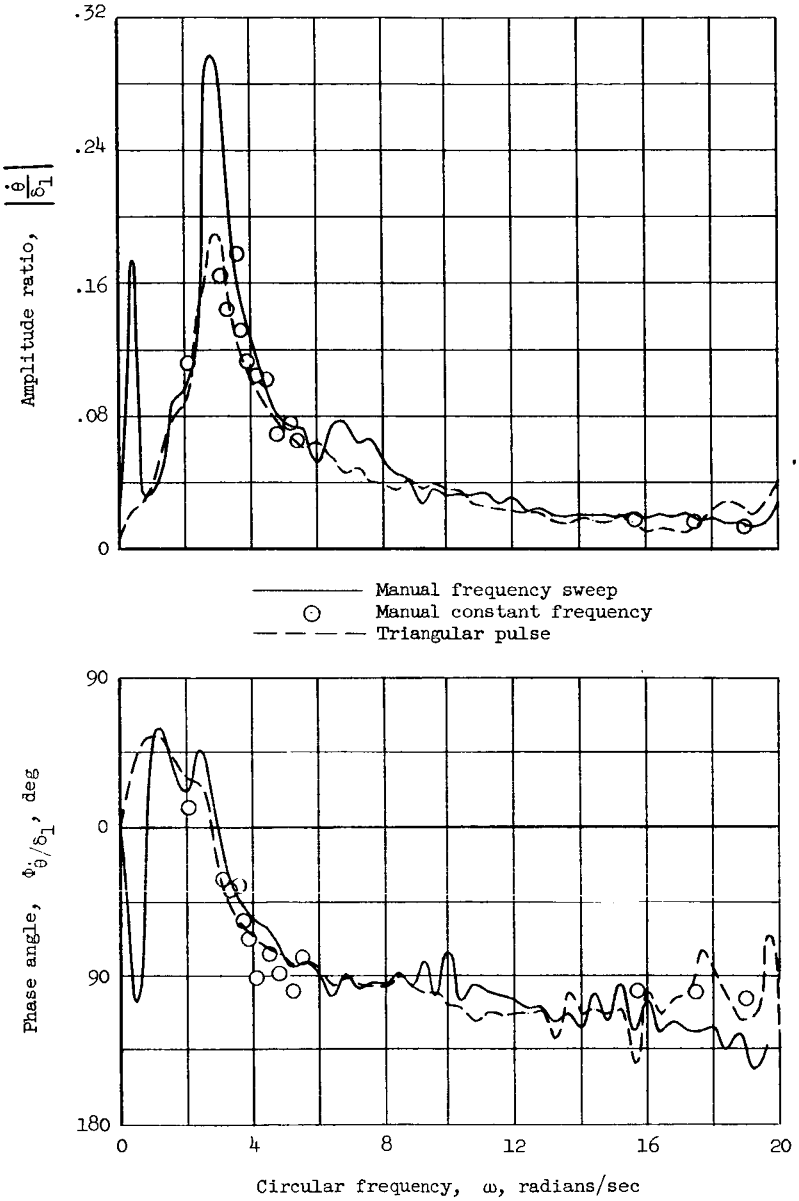
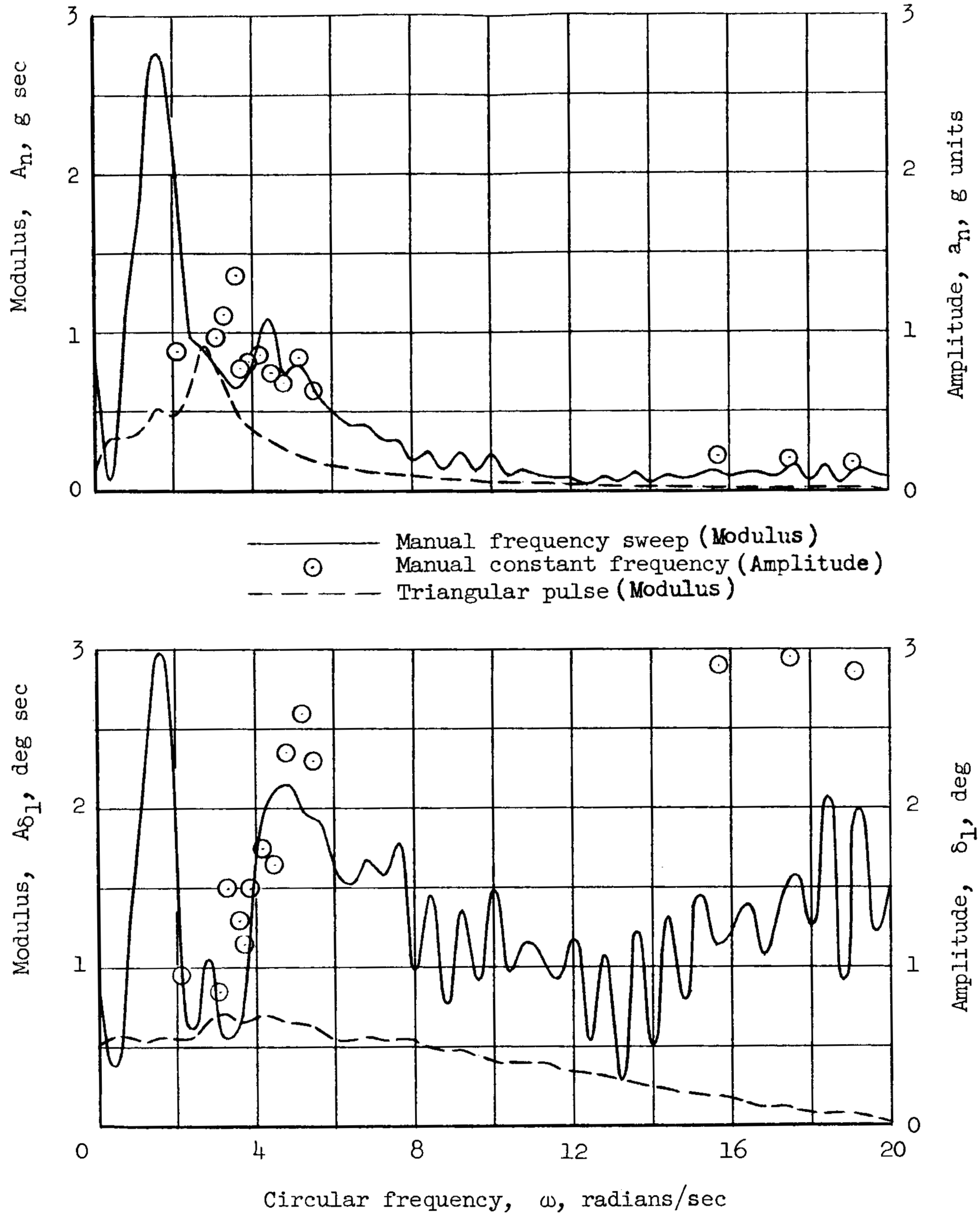


(b) Amplitude ratio and phase angle between stabilizer deflection called for and pitching response.

Figure 3.- Concluded.



(a) Harmonic content of input and output.

Figure 4.- Frequency response in normal acceleration at a Mach number of 0.85 and an altitude of 35,000 feet from another 20-second frequency sweep sample with comparison with results from steady-state and triangular-pulse inputs.

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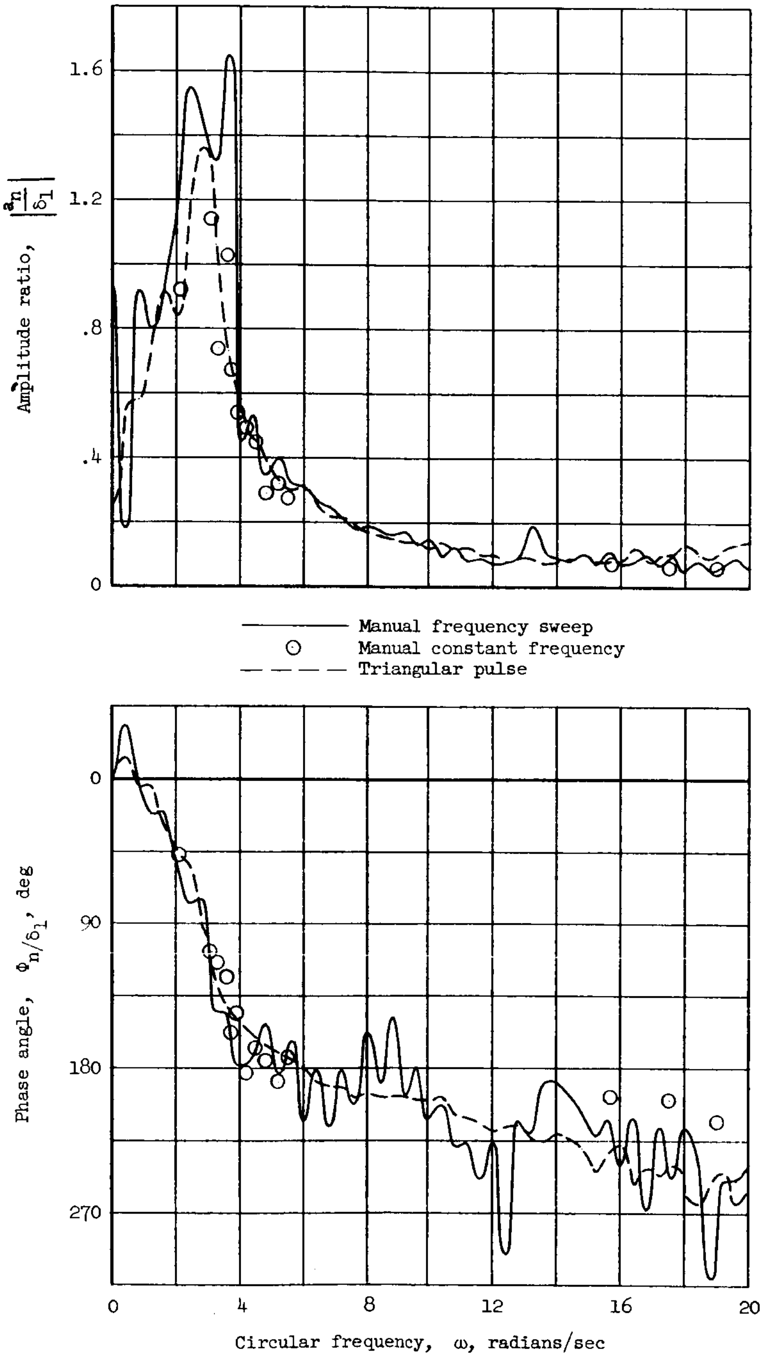
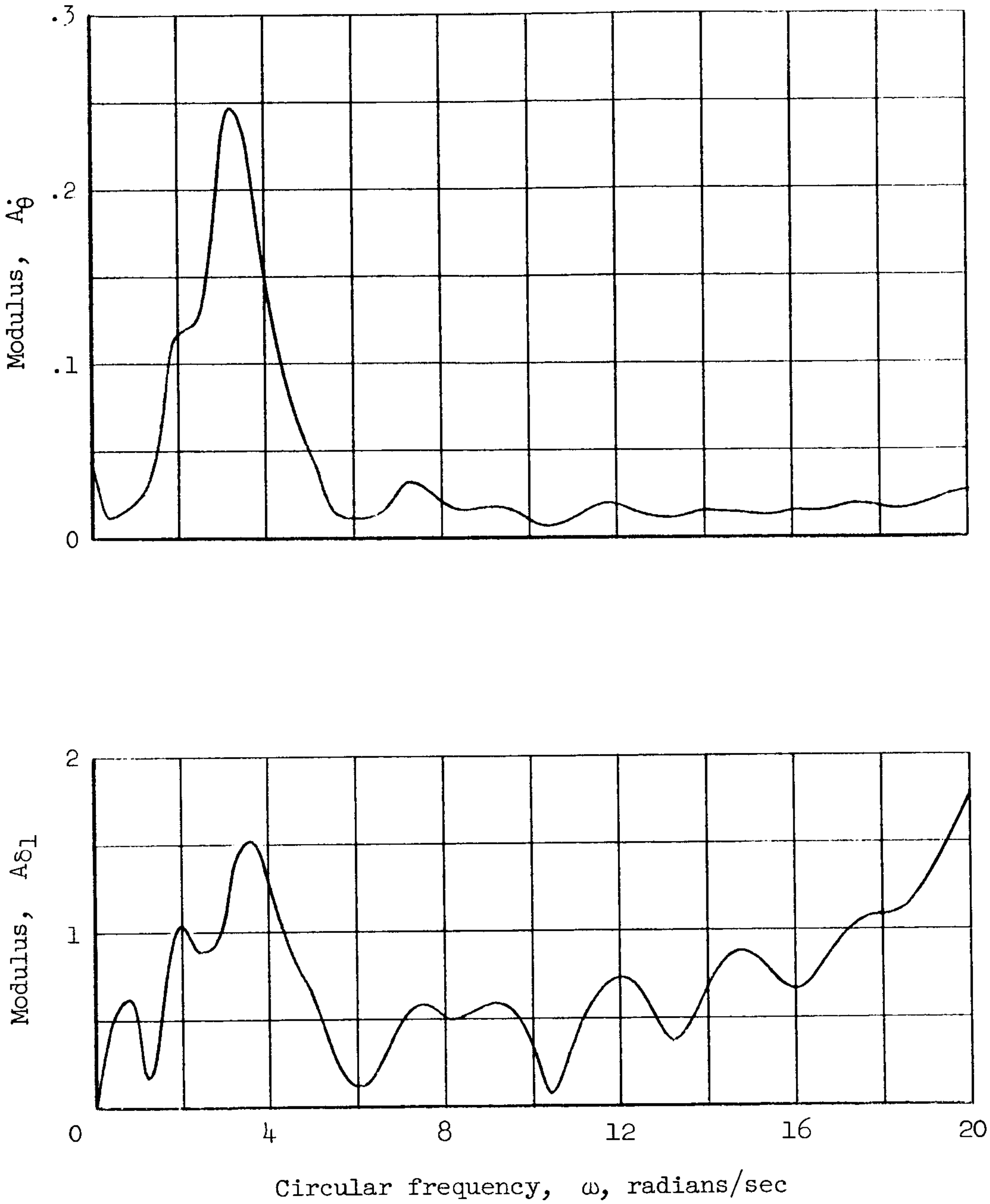


(b) Amplitude ratio and phase angle between stabilizer deflection called for and normal-acceleration response.

Figure 4.- Concluded.



(a) Harmonic content of input and output.

Figure 5.- Frequency response in pitch from a manual frequency sweep run for which the results are poorly defined whenever the modulus of the input falls below 0.3 deg-sec.

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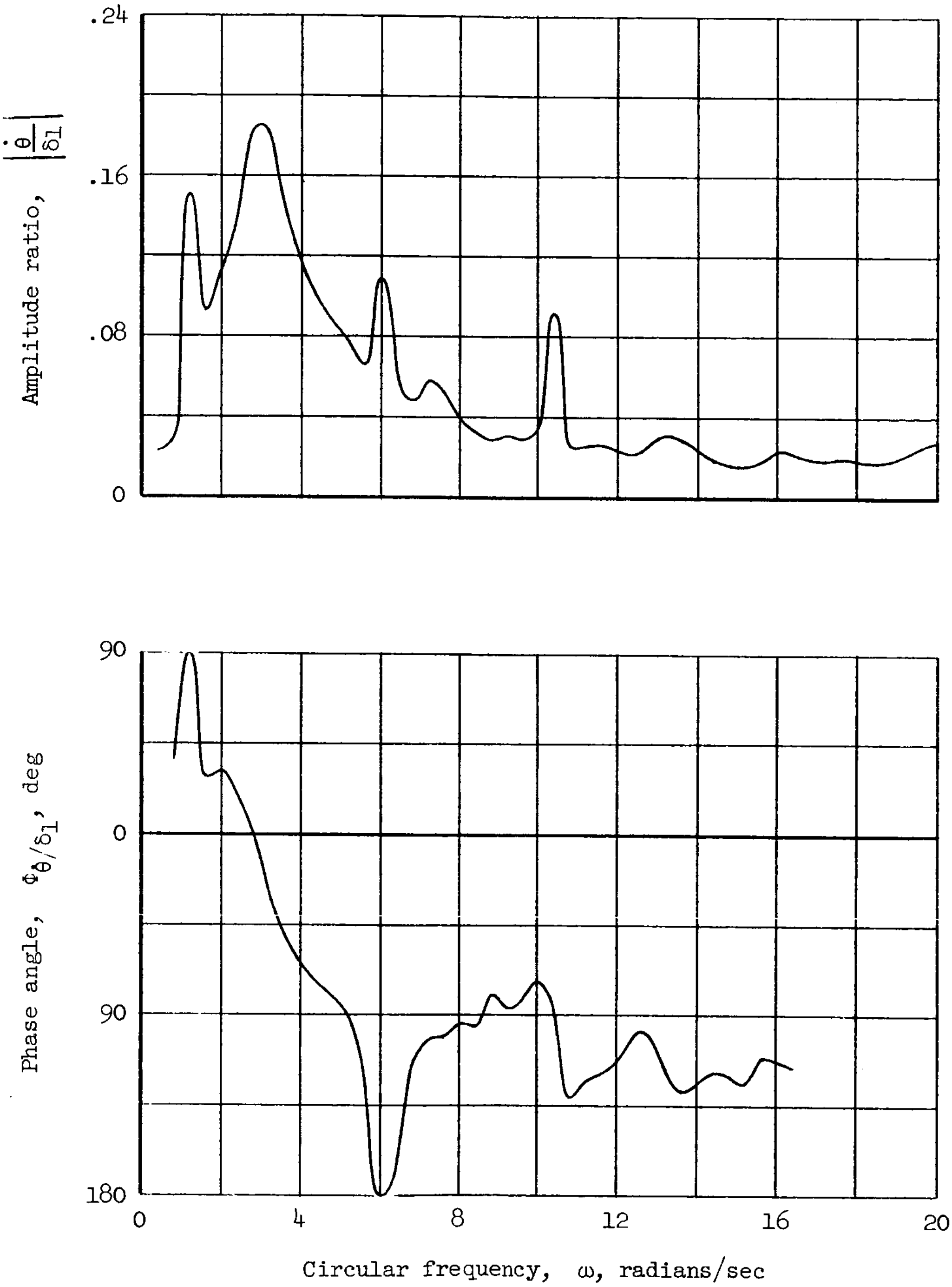
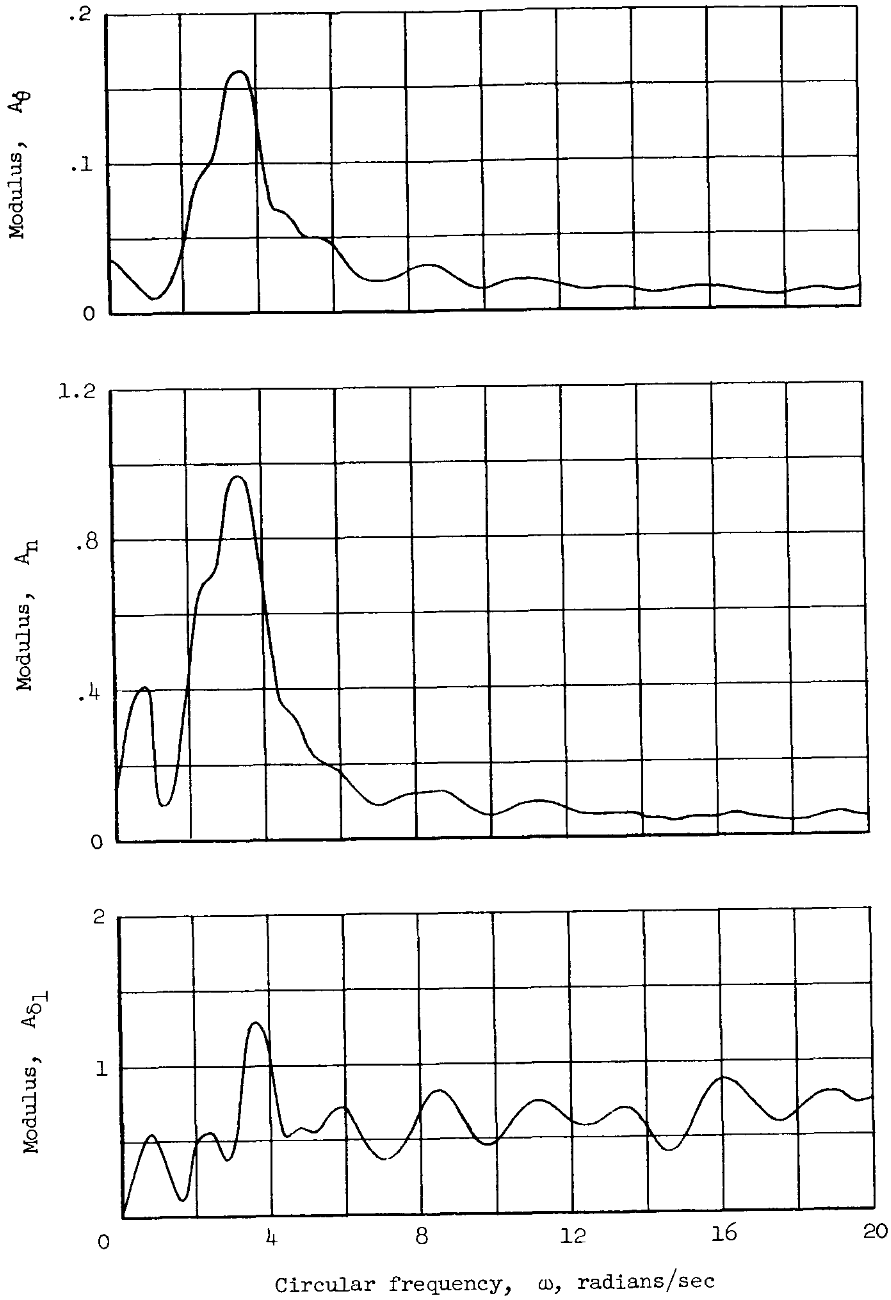


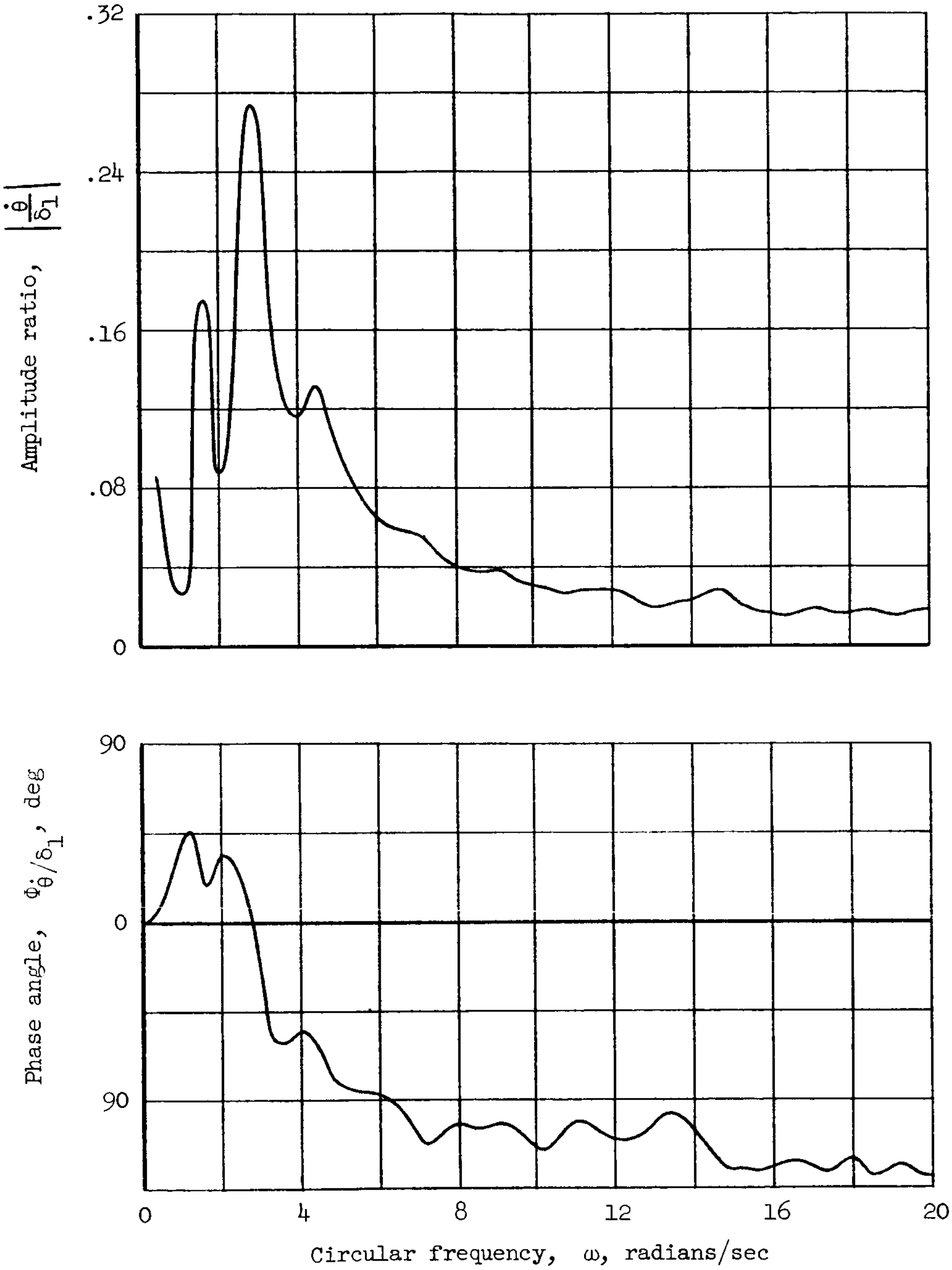
(b) Amplitude ratio and phase angle for $\dot{\theta}/\delta_1$.

Figure 5.- Concluded.



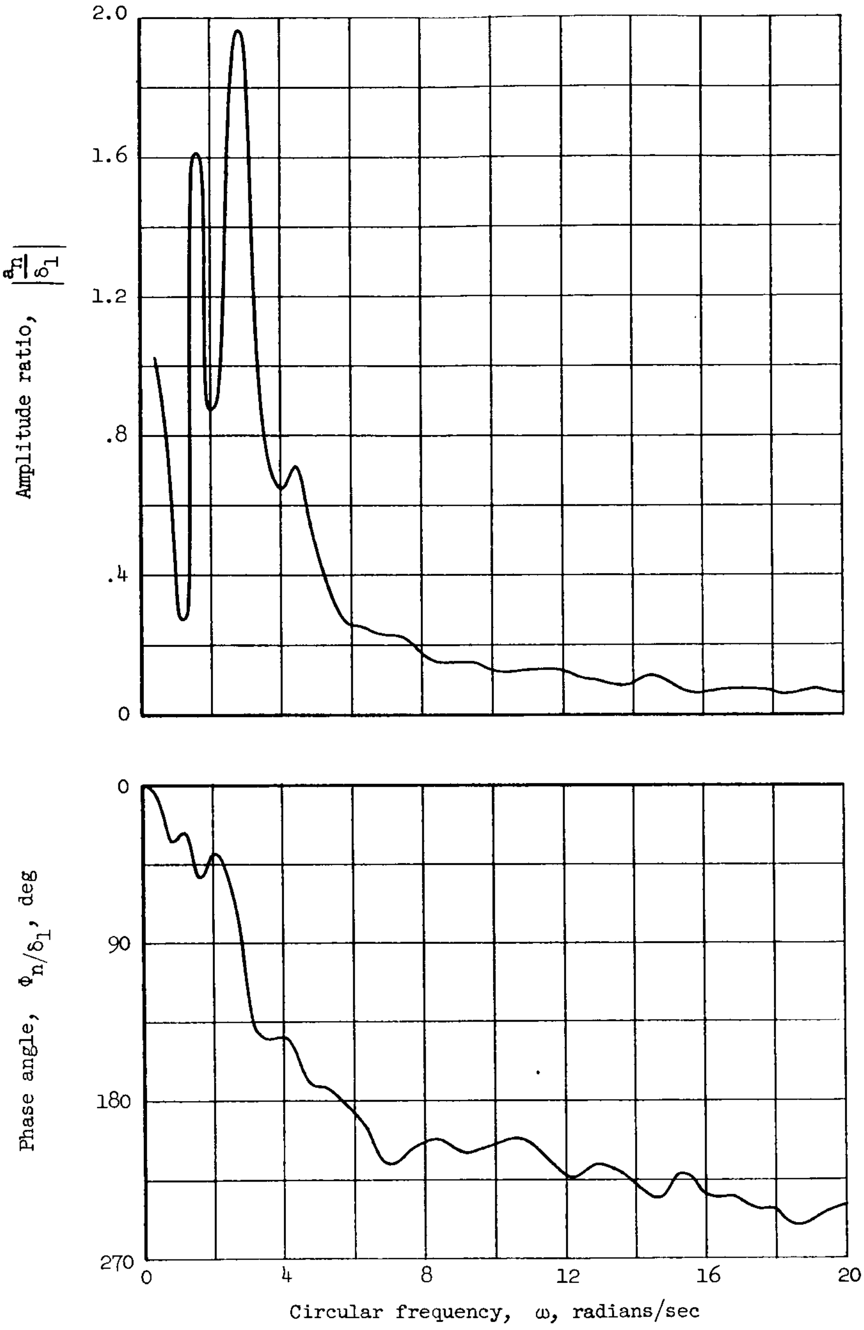
(a) Harmonic content of input and output.

Figure 6.- Frequency response in pitch and normal acceleration at a Mach number of 0.85 and an altitude of 35,000 feet as determined from an abbreviated (5-second) frequency sweep run.



(b) Amplitude ratio and phase angle for $\left|\frac{\dot{\theta}}{\delta_1}\right|$.

Figure 6.- Continued.



(c) Amplitude ratio and phase angle for $\left|\frac{a_n}{\delta_1}\right|$.

Figure 6.- Concluded.

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